Effects of Forestry Activities on Insect Biodiversity in Abukuma, Kanto Region, Temperate Japan

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Introduction

Forestry activities affect animal biodiversity in various ways and degrees by modifying forests and their surroundings that are inhabited by such organisms. As animals perform various functions in the forest ecosystem, forestry practices should be selected so as to retain, or at least not produce severe deterioration of, their biodiversity. However, it is often unclear how different animal groups respond to particular forestry practices in terms of their biodiversity.

In the Abukuma area, northern Kanto, temperate Japan, there have typically been two types of forestry practice: 1) small scale clear-cutting of deciduous broad-leaved trees, and 2) conversion of broad-leaved stands into coniferous plantations of Japanese cedar (*Cryptomeria japonica*) and hinoki cypress (*Chamaecyparis obtusa*). In order to learn how these practices have affected animal biodiversity, we investigated species richness and assemblage of insects in differently managed stands. Because insects not only have the greatest biodiversity among animals (e.g. Grimaldi and Engel 2005), but perform a wide range of ecosystem functions (Weisser and Siemann 2004), we consider them to be some of the best target animals for evaluation of effects of forestry activities on biodiversity.

In this report, we first show how species richness of insects changes with the age of regeneration stands after clear-cutting of broad-leaved trees, with special reference to differential responses among insect taxa (cf. Makino et al. 2006). Besides insects, some mites (Acari) were also monitored. Secondly, we compare insect assemblage as well as species richness between broad-leaved and conifer stands of various ages, focusing on longhorn beetles (Coleoptera, Cerambycidae) (cf. Makino et al. 2007). Longhorn beetles are useful indicators of forest conditions because they are mainly xylophagous in larval stages and frequently visit flowers as adults, thus are expected to be sensitive to changes in forest conditions. Finally, we briefly discuss effects of forestry on insect biodiversity in this region.

Materials & Methods

Study areas

This study was conducted in 2 areas, Ogawa and Satomi, Ibaraki Prefecture, central Japan. Both areas had plantations of *Cryptomeria japonica* and *Chamaecyparis obtusa*, though the percentage of plantation areas was much larger in Satomi than in Ogawa (94% vs. 47% of total forested area). Ogawa is located at the southern edge of the Abukuma Mountains in Kitaibaraki (approximately 36° 56' N, 140° 35' E, 580–800 m a.s.l.). In deciduous broad-leaved forests in the area, the dominant large trees are *Quercus serrata*, *Quercus mongolica* and *Fagus crenata*. Broad-leaved stands have repeatedly been clear-cut on a small scale to

collect bed logs for mushroom culture, and this continues in the present. In addition, the number of conifer plantations converted from broad-leaved stands greatly increased after the Second World War. These practices have resulted in a mosaic-like landscape composed of secondary broad-leaved stands and conifer plantations of different ages. We selected 10 plots in broad-leaved stands to form a chronosequence from 1 to over 100 years after clear-cutting (Table 1). All plots were located within an approximately 30 km^2 area. Satomi (approximately 36° 50' N, 140° 34' E, 700-800 m a.s.l.) is about 10 km southwest of Ogawa area. We selected 8 plots of Japanese cedar plantations in an approximately 10 km^2 area in Satomi. The conifer plots also formed a chronosequence from 1 to 76 years after plantation.

Table 1. Study plots and the number of longicorn species collected in Ogawa (broad-leaved plots) and Satomi (conifer plots) (modified from Makino et al. 2007).

Area	Plot code	Age (year)	Area (ha)
Ogawa	O1	1	3
	O4	4	5
	O12	12	4
	O24	24	24
	O51	51	10
	O54	54	14
	O71	71	19
	O128	>100	98
	O174	>100	11
	O178	>100	10
Satomi	S3	3	4
	S7	7	6
	S9	9	5
	S20	20	5
	S29	29	14
	S31	31	12
	S75	75	3
	S76	76	3

Monitoring methods and target animals

Target animals were selected from a variety of taxa representing different ecological functions. All insects and mites were collected in the 10 broad-leaved plots in Ogawa in 2002; for longicorn beetles, additional collection was made in the 8 conifer plots in Satomi in 2003. Targets and collection methods are as follows. Insect traps, when used, were placed well inside the study plots to avoid possible edge effects.

Butterflies: One-hour transect counts were made twice a month from April to October between 9:00 and 15:00 (cf. Inoue, 2003). Species and number of butterflies sighted were recorded at each census. **Moths**: A single portable light trap (Okochi, 2002) was left overnight at each of the monitoring sites twice in August, and moths trapped inside were collected the following morning. All plots were censused on the same nights. **Ground beetles**: Pitfall traps were used, made from transparent plastic bottles (77 mm diameter, 158 mm height) with three small holes (about 5 mm in diameter) in the middle for drainage of rainwater. In each plot, ten pitfall traps were aligned in three parallel lines, with a distance of about 10 m between traps. Trapped insects were collected every two weeks from April to November. **Tube-renting bees and wasps**: Nesting traps, which were made of 16 bamboo stalks (approximately 8 to 16 mm in diameter) and four reeds (6 mm),

were used. At each plot, nine traps were tied to tree trunks or wooden posts (where no substrate trees are available) at 1.5 m above the ground in April, and removed in November. Immatures found in the traps were reared until eclosion for identification. **Longicorn beetles, hoverflies and fruit flies**: Collection was made with Malaise traps (Golden Owl Publishers, 180 cm long, 120 cm wide, 200 cm high). Five traps were set in April at each plot at intervals of 10 m. Collection of trapped insects was made every two weeks as in pitfall traps. **Ants**: Litter sampling was made between July and August along a 100 m (or 200 m in a few sites) transect line in each plot, and ants were hand-sorted. Additionally, pitfall traps (disposable plastic cups) were set along the same line at 10 m intervals for a maximum duration of three days. **Oribatid mites and collembola**: A cylindrical core (25 cm^2 x 5 cm high) of soil was removed from eight divisions (4 x 2 m) of a quadrat (8 x 8 m) in April, August, and November; soil arthropods were later extracted with Tullgren funnels (cf. Hasegawa et al., 2004). **Mites associated with mushrooms**: Mushroom fruiting bodies were sampled in each plot once a month from April to November. Mites were hand-sorted from mushrooms and identified under a microscope.

Forest characteristics

In order to learn how forest characteristics affect insect biodiversity, we made plant censuses in the above plots. A 100 m line transect was established at each plot from September 2000 to October 2003. All trees and vines of at least 2 m in height and at least 5 cm in DBH were counted and their GBH (girth at breast height) was measured in a total of forty 5 x 5 m quadrats along both sides of the 100 m transect line mentioned above; the frequency of trees smaller than 5 cm in DBH in the 40 quadrats was also censused. Forest floor vegetation with a height of less than 2 m (forest floor plants) was censused following the Braun-Blanquet method for a 1 x 1 m subquadrat in each 5 x 5 m quadrat.

Analyses of longicorn assemblages

Canonical Correspondence Analysis (CCA) of longicorn beetles was performed with Canoco for Windows, Version 4.5 (ter Braak and Smilauer 2002). Only those species with a total count of at least 3 individuals were used in CCA. As environmental variables, we selected the following plant community indices: species richness of plants for 3 size classes (trees with DBH $\geq$ 5 cm, trees with DBH <5 cm, and forest floor plants), the density of trees with DBH $\geq$ 5 cm and maximum and average diameter of tress at breast height. In this analysis, the scores of the 1st and 2nd axes in Detrended Correspondence Analysis (DCA) for the plant community group ordination for the 3 size classes were also used, in order to investigate the effects of plant species compositions on communities of longicorns. In DCA of plants, species with at least 3 individuals in total were used, and population data were transformed using logarithmic transformation, log10(x+1). In DCA of trees with DBH $\geq$ 5 cm, the 1-year-old site (O1) and the 4-years-old site (O4) were excluded because there were no trees of this size class. Likewise, in the DCA of forest floor plants, the 1-year-old site was excluded. Population data were transformed using logarithmic transformation, log10(x+1). Environmental variables were tested using forward selection of variables with Monte Carlo test using 499 unrestricted permutations ($P < 0.05$).

Results

Insect species richness in relation to the age of broad-leaved stands

Species richness of insects in broad-leaved stands in Ogawa is shown in Figure 1, in which the number of species is represented as a proportional rather than absolute value. The response of species richness to the stand age was classified into the following three types. Type I (butterflies, hoverflies, fruit flies, tube-renting bees and wasps, and longicorn beetles): species richness was high in grasslands or in early stages of succession, while much lower in older forests. Type II (mites associated with mushrooms): species richness was low in early stages of succession, becoming greater as forests mature. The number of mushroom species showed a similar response to the mite. Type III (moths, ants, ground beetles, oribatid mites, and collembolas): species richness did not greatly vary with forest age. However, the taxa showing Type III response often had different community compositions among the plots (for soil animals, see Hasegawa et al. 2004). Therefore, uniform species richness did not mean a homogeneous species composition among ages of the stands.

Difference in longicorn assemblage between broad-leaved and conifer stands

A total of 106 longicorn species was collected in Ogawa and Satomi. The average number of species was larger in broad-leaved plots (35.8 SD7.7) in Ogawa than in coniferous ones (22.9 SD8.7) in Satomi (ANOVA, P=0.004). Both in Ogawa and Satomi, species richness was larger in young than in older stands (Fig. 1).

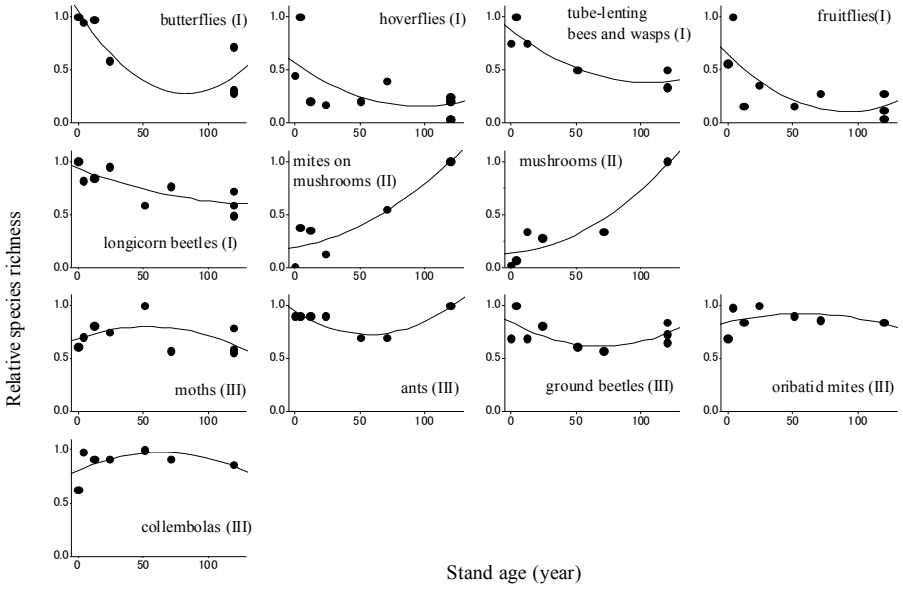

Fig. 1 Relationship between the species richness and the age of regeneration stands after clear-cutting in insects and other organisms in Ogawa, Abukuma area. The notation I, II, or III in parentheses stands for the type of response shown by the particular taxon. The species richness decreases with stand age in Type I, increases in Type II, and does not greatly change in Type III. Lines are quadratic polynomial approximations. Modified from Makino et al. (2006).

The CCA ordination divided the 18 plots into three groups (Fig. 2), which correspond to the following three stand types: initial stage stands, broad-leaved stands, and conifer stands. Species richness was largest in initial stage stands, followed by broad-leaved, and smallest in confer stands; the difference was significant among the three types (ANOVA, P<<0.001) as well as between any pair (corrected for multiple comparison with Bonferroni adjustment).

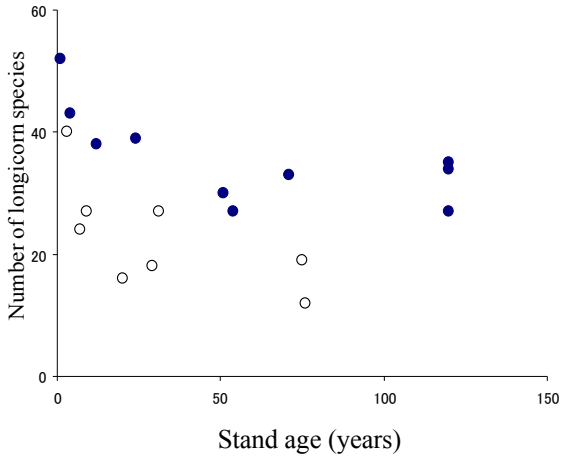

Fig. 2 The number of longicorn species collected with Malaise traps in stands of different ages. Solid and open circles stand for broad-leaved stands and conifer (*Cryptomeria japonica*) plantations, respectively.

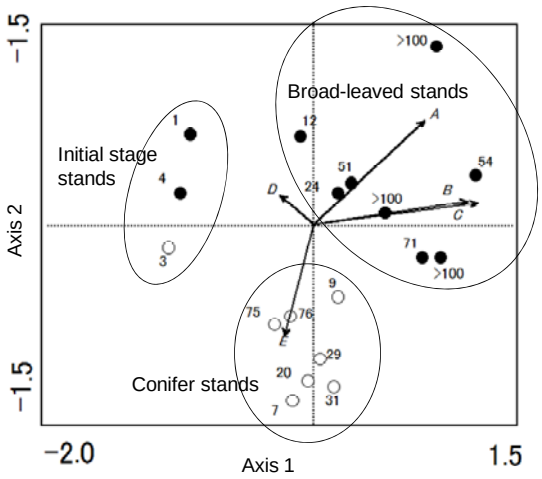

Fig. 3 Ordination of longicorn assemblages by canonical correspondence analysis (CCA). Three forest types are identified. Solid and open circles are as in Fig. 2, and figures show stand ages. Arrows with suffix A to E show variables of forest characteristics, which were significantly related with the division among the three forest groups. See text for more explanation. Modified from Makino et al. (2007).

The CCA analysis selected the following five variables of forest characteristics that are significantly related (P< 0.05) with longicorn species compositions: scores of DCA 2nd axis of forest floor plants (arrow

A in Fig. 3), the maximal DBH of trees (arrow B), the number of species of trees with DBH ≥ 5 cm (arrow C), species richness of forest floor plants (arrow D), and DCA 1st axis of trees with DBH ≥ 5 cm (arrow E). The arrows B and C, both representing the maturation process of forest growth, were nearly parallel to the 1st axis of the CCA diagram (Fig. 3), and explained the discrimination of longicorn species composition between the two older forest types (conifer stands and broad-leaved stands) and the young one (initiation plots). In contrast, the arrows A and E had more vertical directions, and explained the discrimination between broad-leaved and conifer stands. The arrow D representing the species richness of forest floor plants was short, indicating that its effect on the longicorn species composition is marginal.

Discussion

Effects of stand age on insect biodiversity

We showed that the effect of stand age on species richness was not uniform among the taxa monitored. This may be partly due to differential dependence on herbaceous plants. The taxa showing the Type I response, for example, are herbivores during the larval stage, and/or largely depend on flowers for carbohydrates as adults. Many butterfly species live in grasslands and utilize herbaceous plants as hosts. Even species whose larval hosts are trees visit herbaceous plants for nectar as adults (Inoue, 2003). Tube renting bees and wasps probably collect nectar and pollen, or hunt prey (for example, lepidopterous larvae, spiders, and grasshoppers) respectively, in grasslands or in very young and open stands. Although most longicorn beetles feed on dead trees during the larval period, adult insects frequently visit flowers. Then, for taxa showing Type I response, abundance of flowers may be an important factor that contributes to the high species richness observed in plots of early stages of succession. In contrast, those organisms which showed Type II or III responses (mites, soil animals, etc.: Fig. 1) do not seem to require or depend on as abundant a flower resource as do the Type I taxa.

Whatever the underlying mechanisms are, the different responses to the stand age among the taxa indicate that combinations of stands of various ages, or heterogeneously arranged stands, contribute to the maintenance of insect diversity at the landscape level. In Abukuma area, the traditional forestry utilizing regeneration stands by repeating a small-scale clear-cutting has produced open, grassland-like stands as well as middle-aged stands on the one hand, while retaining old forests on the other. This seems to have generally been giving a positive effect on insect diversity.

Effects of conifer plantation on longicorn diversity

The conifer stands, which were monocultures of Japanese cedars, had much smaller numbers of longicorn species than similar-aged broad-leaved stands, except for young plantations (Figs. 3, 4). Probably, the Japanese cedar is not an attractive host plant for longicorns. Kojima and Nakamura (1986) present host records of 468 Japanese longicorn species, of which 30 (6%) feed on (or emerge from) Japanese cedar. However, only two species are recorded as specialists of Japanese cedar or related conifers: the other species have wider host ranges including broad-leaved trees (Kojima and Nakamura 1986). This suggests that a great majority of Japanese longicorn species can live without Japanese cedar, which dominates forested areas in many parts of Japan. On the contrary, a significant decrease in broad-leaved forests and increase in

cedar plantations may lead to impoverishment of longicorn faunas, because most species simply have hosts other than Japanese cedar.

An extensive conifer plantation may lead not only to impoverishment of longicorn diversity but to degradation of ecosystem functions that they possibly perform in pollination or in decomposition of dead trees. This is because longicorns frequently visit flowers as adults for pollen and/or nectar feeding, and they principally feed on dead or weakened trees as larvae thus facilitating decomposition by fungi or microorganisms. We urgently need to study the nature and magnitude of conifer plantation on ecosystem functions not only of longicorn beetles but insects in general.

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